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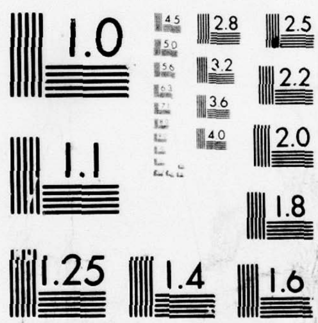

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INNOVATIONS IN DIGITAL IMAGE PROCESSING

by

Albert N. Williamson

Mobility and Environmental Systems Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Final Report

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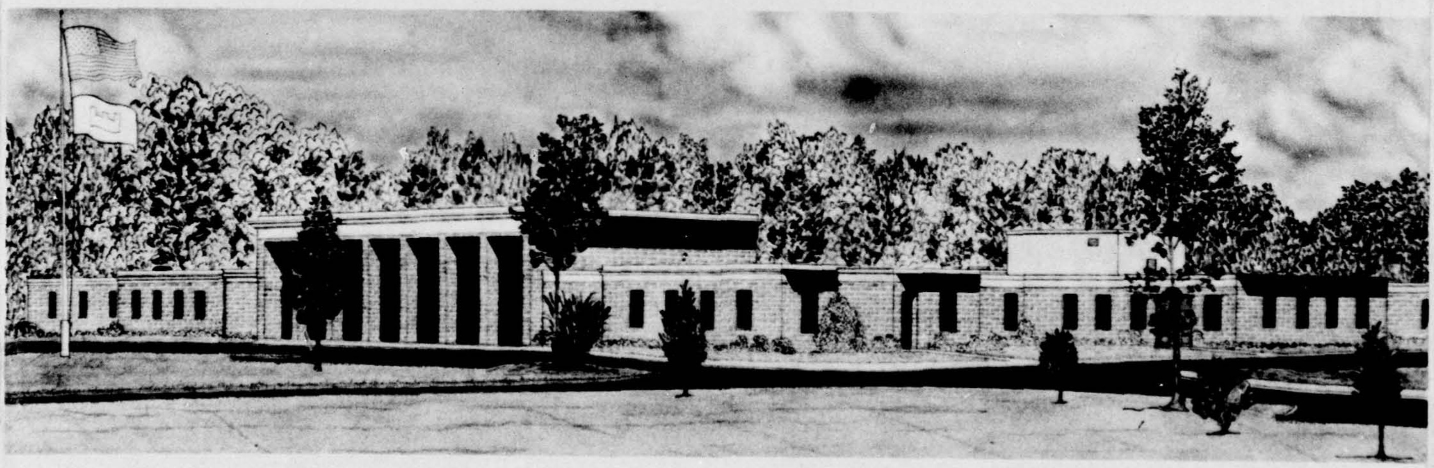

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This paper discusses a technique for producing suspended material distribution maps by spectrum matching and two different techniques for detecting time-dependent changes recorded by the Landsat MSS--computer-generated false color composites for visual interpretation and detection by pixel-for-pixel comparison.

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Foreword

This paper was prepared for presentation at the International Symposium on Image Processing--Interactions with Photogrammetry and Remote Sensing, held at the Technical University in Graz, Austria, during 3-5 October 1977. The symposium was sponsored by the International Society for Photogrammetry, Commission III, Working Group on Image Processing; the Austrian Solar and Space Agency; and the Austrian Federal Bureau for Standards and Mapping.

Included in the paper are some of the results of a course of study and development at the U. S. Army Engineer Waterways Experiment Station (WES) that have produced a family of computer programs and algorithms designed to extract meaningful geometric and radiometric information from digitized image data, interpret the data, and depict the results as tabular lists printed with conventional line printers or as images on photographic film that can be used to make photographic images, maps, or charts. Specifically described are the equipment used for image data processing and applications of image data processing techniques for (a) suspended material distribution mapping, (b) production of color composites from Landsat computer-compatible tapes, (c) change detection, and (d) generation of color separations for offset printing.

The study and development referred to herein were conducted by personnel of the Data Handling Branch (DHB), Mobility Systems Division (MSD), Mobility and Environmental Systems Laboratory (MESL), WES, under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and A. A. Rula, Chief, MSD. The work was accomplished by Messrs. J. L. Smith, Chief, DHB, A. N. Williamson, and J. G. Kennedy, under the direct supervision of Mr. Smith.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors of WES during the period of the study and development of the image data processing capabilities and preparation of this paper. Mr. F. R. Brown was Technical Director.

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INNOVATIONS IN DIGITAL IMAGE PROCESSING

by

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Introduction

The term "digital image processing" connotes a variety of techniques that may vary substantially in sophistication and complexity. For example, some practitioners digitize a photographic image by manually following the boundary of each significant feature in the image with a device that will measure and record in digital form the Cartesian coordinates of points defining the boundary. Although the resulting data base may be small, very elaborate and often complicated computer algorithms requiring the use of large computers are needed to process the polygons defined in this manner. At the opposite end of the spectrum are those practitioners who use scanning devices to digitize photographic images by measuring and recording in a digital format the optical density of points that fall in a carefully controlled pattern on the surface of the image. Although the resulting digital data bases may be very large, the algorithms required to process the data can be relatively simple and can often be used on comparatively small computers.

Equipment Used

Image data processing as it is practiced at the U. S. Army Engineer Waterways Experiment Station (WES) utilizes the latter technique. Two primary items of equipment are employed--a PDP-15 computer and a computer-controlled film reader/writer.

Computer and peripheral equipment

The PDP-15 computer has 16,000 words of magnetic core storage and two disk storage units. Input and output of digitized image data are accomplished by means of magnetic tapes. A Tektronix Model 4014-1 cathode ray tube terminal is used for operator control of computer operation and observation of the digitized imagery. A Versatec Model LP-860 printer is used for hard-copy output.

Film reader/writer

The film reader/writer (Figure 1) is an Optronics International, Inc., Photomation Mark II System. This system is an electromechanical drum-type film-scanning and film-writing system designed to accept film sizes up to and including 22.8 by 22.8 cm (9 by 9 in.). In the film-reading or input mode, a film transparency is clamped to a drum so that the film adheres exactly to the machined cylindrical surface of the drum. A light source and a photo detector are mounted on opposite arms of a carriage within which the drum rotates. An opening in the drum allows light from the source to be transmitted through the transparency to the detector. As the drum rotates, the optical density of successive square spots (pixels) on the film along the circumference of the drum (Y direction) is measured at selected raster intervals. The pixels can be 0.0125, 0.025, or 0.050 mm in size. The raster interval is normally selected to be equal to the pixel size. After each drum revolution, the carriage is stepped in the axial (X) direction a distance equal to the raster interval and the process is repeated until the desired area of the film has been scanned.

The output of the photo detector is amplified and converted to digital form; the results are recorded on computer-compatible tape (CCT) as values between 0 and 255. Transparencies can be scanned without filters or using a blue, green, or red filter to extract information from specific bands on such items as color and color-IR photos.

The information content of the CCT can be better understood by mentally placing a uniform grid comprised of square cells over a photographic image. Each cell in the grid corresponds to a pixel. As the scanner drum rotates, an optical density measurement is made for each

cell in the first column of the grid (Y direction). At the end of the first column of cells, the carriage is stepped one raster interval in the X direction to align with the next column of cells, and an interrecord gap code is recorded on the CCT to signify the beginning of measurements of a new column of cells. This process is repeated until the optical density of the last cell in the grid is measured. An end-of-file code is then recorded on the CCT, thus concluding the image-scanning process. The CCT therefore contains values for the optical density of each cell in the grid. In addition, the location of each measurement with respect to all other measurements is implied by the location of each value recorded on the CCT with respect to all other values recorded. The value for any cell (pixel) can be located on the CCT in terms of its x-y position simply by counting interrecord gap codes to find the desired row (y-value) and counting the pixel values to find the desired position (x-value). The integrity of both the optical density and the spatial position of each measurement is thus maintained as is required for reconstruction of the data in the form of a photographic image. CCT's recorded in this format are commonly referred to as being in image format.

In the film-writing or output mode, the film reader/writer is equipped with a rotating drum and an optical system consisting of a light - emitting diode (LED), a selectable aperture, and a lens system that focuses a spot of light from the LED onto the periphery of the drum. The drum is housed in a light-tight enclosure, which is demountable and is removed to a photographic darkroom to load and unload the film. A piece of film is clamped to the outside of the drum. As the drum rotates, the light intensity of the LED can be modulated incrementally through a range from 0 to 225 to expose the film. Kodak Linagraph Shellburst film, Type 2474, is used since this is the optimum film for this application.

The film can be exposed at the same pixel size and raster interval as used in the reading mode. As the drum rotates, the carriage supporting the optical system is stepped incrementally in the axial (X) direction

at the selected raster interval until the total area of the film or the area of interest has been exposed.

The instrument is controlled by a minicomputer so that real-time manipulation of the digitized density data can be used to produce a number of photographic effects. However, for this capability to be used successfully, very careful control over the photographic process and knowledge of the relation between the digital input and the photographic output of the film writer are required.

Control of the photographic process is achieved in the following manner. Prior to use, the film is stored at approximately 0°C to minimize shift in speed and color sensitivity. Immediately following exposure, the film is developed to minimize latent image shift. Exposed film is developed for 8 min in D-19 developer at a temperature of 20° ± 0.25°C.

To establish the relation between the CCT values (i.e. the 256 light-intensity levels through which the LED can be modulated) and the gray shades on exposed film, a film is "written" using, in place of the CCT of an image, a computer-generated CCT containing a set of 21 values between 0 and 255 (second column in tabulation below) that will result in a gray step wedge on film with optical density steps of approximately 0.15 (third column in tabulation below). This film is developed, and the optical density of each step is measured with a W. M. Welch Co., Model 3853J, Densichron. An example of the resulting values is given in the fourth column of the tabulation below.

Step No.	CCT Value	Desired Optical Density	Measured Optical Density
1	000	0.00	0.10
2	013	0.15	0.12
3	026	0.30	0.17
4	038	0.45	0.28
5	051	0.60	0.44

Step No.	CCT Value	Desired Optical Density	Measured Optical Density
6	064	0.75	0.64
7	077	0.90	0.80
8	089	1.05	0.94
9	102	1.20	1.06
10	115	1.35	1.17
11	128	1.50	1.29
12	140	1.65	1.42
13	153	1.80	1.57
14	166	1.95	1.70
15	179	2.10	1.84
16	191	2.25	1.94
17	204	2.40	2.04
18	217	2.55	2.15
19	230	2.70	2.24
20	242	2.85	2.26
21	255	3.00	2.24

Examination of the values listed in the tabulation shows that the relation between CCT values and measured optical density is nearly linear between step 3 and step 16 suggesting that visual differentiation of gray shades can be best accomplished by selecting CCT values somewhere within these limits. Unfortunately, these limits are substantially reduced when the image produced on photographic film is used to make a print on photographic paper. Experience at the WES has shown that when prints are to be made, the usable film density range (0.17 to 1.94) is reduced to a range of approximately 0.28 to 1.70 (step 4 to step 14 in the tabulation)--the range varies somewhat with paper age, development procedures, etc.

Procedures and Applications for Image Processing

The launch in late 1972 of NASA's first Landsat satellite (formerly called Earth Resources Technology Satellite) provided the impetus needed to push the technology of image data processing to a position of prominence at the WES. Since that time over 30 different computer programs have been developed for the purpose of (a) extracting meaningful geometric

and radiometric data, (b) interpreting these data, and (c) depicting the results as tabular lists printed with conventional computer line-printers or as images on photographic film that can be used to make photographic images, maps, or charts. (A list of operations that can be performed with existing computer programs is given in Appendix A.) Most of these programs perform a specific function, such as rectifying data to achieve geometric accordance with a map or another image, and are used in different combinations depending upon the job to be performed. However, all of the programs are usable either directly or indirectly with data recorded on Landsat multispectral scanner (MSS) CCT's or with CCT's produced with the Photomation System. The utility of this approach to digital image processing can be seen in the applications described in the following paragraphs.

Spectrum matching

Spectrum matching is the process of matching the reflectance spectrum of one or more features in an area with a reference spectrum stored in computer memory. To retain the integrity of the scene, spectrum matching must be done on a pixel by pixel basis.

The reflectance spectrum of a material is normally defined by a curve of the intensity of the reflected radiation as a function of wavelength and might appear as the example shown in Figure 2a. The Landsat MSS, however, uses filters to separate the reflected radiation of each pixel into four spectral bands. Detectors convert the energy in each band to electrical analogs, which, in turn, are converted to digital form. Unlike the spectrum derived from the laboratory spectrophotometer (Figure 2a), a reflectance spectrum derived from the MSS will actually be a histogram (Figure 2b) that shows the average intensity of reflected radiation in each of the four MSS wavelength bands. In this context, if an MSS such as the Bendix 24-channel scanner was used, 10 channels would define the same spectrum in terms of a histogram for each of the 10 wavelength bands with the results being as shown in Figure 2c. Thus, the accuracy and clarity of spectrum definition increases as the number of channels (spectral bands) that are observed increases.

Reference spectra may be derived from one of three possible sources: (1) prediction models, (2) ground truth measurements, or (3) ground truth coupled with remote sensor measurements. The exact procedure used depends to a very large extent on the intended purpose of the multispectral remote sensor data acquisition. An example is described in the following paragraphs.

During the 1973 flood in the Lower Mississippi River Valley, an enormous volume of water flowed down the river placing heavy stress on protective structures along its lower reaches. To relieve some of the pressure, the Bonnet Carre Floodway that connects the Mississippi River with Lake Pontchartrain (Louisiana) was opened to allow a portion of the river water to flow into the lake. However, the fact that water containing high concentrations of suspended materials was flowing into the relatively clean water of Lake Pontchartrain caused concern in the oyster and fishing industries in the area. Information was needed on where the suspended materials were being carried in the lake and where the heaviest concentrations were located.

A sampling program was implemented in Lake Pontchartrain in which water samples were taken at a large number of carefully selected points (Figure 3) close to a time (on 4 May 1973) when the Landsat MSS would be taking measurements of the area. The water samples were used to determine by conventional laboratory procedures the concentration of suspended material (in mg/ℓ) at each location.

The reflectance spectrum for each sampling point was determined from radiance values measured by the Landsat MSS. This was done by first producing a digital "map" comprised of band 7 radiance values printed on the "map" according to their corresponding location on the terrain surface. Since band 7 values are always lower for water than for land areas, use of band 7 data allowed the threshold for land-water separation to be easily established and the sampling points to be easily located in terms of scan line and pixel number (sampling point address) on the CCT. The address of the sampling points was then used as input to a computer program that searches the CCT, and extracts and prints the band 4, 5, and 6 radiance values for each sampling point.

Correlations between the reflectance spectra and suspended material concentrations were then established and the reference spectra were defined and assigned a class number. The results are shown in the table below.

Class	Radiance Value, mW/cm^2-sr Landsat MSS Band 4	5	6	7	Suspended Material Concentration (mg/ℓ)
0	Any band 4, 5, or 6 value outside its limit for a given class			0-0.20	Unclassified area
1	1.54-1.77	0.89-1.19	0-0.82	0-0.20	<150
2	1.65-1.83	1.10-1.27	0.70-0.95	0-0.20	150-165
3	1.71-1.88	1.19-1.31	0.86-1.07	0-0.20	>165-180
4	>1.76	>1.27	1.03-1.23	0-0.20	>180
5	Any combination of band 4, 5, or 6 values			>0.20	land

The reflectance spectrum of each pixel was then compared with each of the above reference spectra. When a match occurred, the pixel was identified by the class number corresponding to the spectrum matched and, hence, the suspended material concentration in the area covered by the pixel.

So that the results of spectrum matching would closely conform geometrically to the area covered on the terrain surface by the Landsat scene, the data were then corrected for skew and pixel shape. Skew results because approximately 25 sec are required for Landsat to traverse from the northern extremity to the southern extremity of a scene. During this time the rotation of the earth carries the surface eastward a finite amount. At the latitude of the southern United States where Lake Pontchartrain is located, the surface moves eastward with respect to the satellite orbital path one pixel width (57 m) in about 0.124 sec. In the time that it takes the surface to move eastward the width of one pixel, the satellite has advanced southward along its orbital path a distance equivalent to about 11.6 scan lines. This error is systematic and was corrected by offsetting each successive group of 12 scan lines

to the westward one pixel width. A total of 260 false pixels were inserted on the CCT either at the beginning or at the end of each scan line to bring the adjusted digital array into a rectangular array.

Pixel shape correction is required to compensate for the fact that the film reader/writer "writes" an image on film by exposing an orthogonal array of square spots, whereas the Landsat MSS pixel has a width-to-length ratio of approximately 1:1.38. To correct the data, a copy is made of the CCT with the pixel values of every third and every twentieth scan line duplicated. A suspended material distribution map produced from the resulting tape is "stretched" to achieve the desired geometric conformity.

In the process of producing the suspended material distribution map on the film reader/writer the class numbers were converted to distinguishable gray shades by substituting CCT equivalent values for class codes as follows:

Class	Assigned CCT Equivalent Value
0	255
1	173
2	133
3	93
4	53
5	0

The suspended material distribution map that resulted from this process is shown in Figure 4. Land areas appear black, unclassified areas are white, and suspended material concentrations are identified by gray shades. The high concentration of suspended material at the point of injection into Lake Pontchartrain and the direction of flow of the mass of suspended materials are both clearly discernible.

Change detection

Time-dependent changes that have occurred within an area can be detected by visual inspection and interpretation of a series of images of the area or by digital comparison of image data for the area taken at different times. However, the method that is ultimately used is the one that is the most cost effective and at the same time consistent with the resolution and level of accuracy required.

Two examples of change detection are discussed in the following paragraphs. Although these are not the only methods used for change detection, they are uniquely different from more conventional approaches and serve to exemplify the diversity of approaches that are possible with digital image processing. In the first example, digital processing of Landsat CCT data was employed to produce a set of color separations that were, in turn, used to produce a set of color composite images for interpretation. In the second example, a Landsat scene was digitally corrected to achieve geometric accordance with another Landsat scene of the same area. Then the two scenes were digitally compared to detect changes.

Color composites for visual interpretation of change. Color composites are normally made at the WES on DuPont Cromalin, a photopolymer-coated material that remains sticky until it is exposed to an ultraviolet (UV) light source. An image can be produced on the material by exposing the photopolymer through a halftone positive transparency on which various shades are obtained by controlling the number of black (opaque) dots per unit area on the film.* Where one or more dots prevent the UV light from reaching the photopolymer, the material remains sticky. Other areas lose their stickiness. The photopolymer can then be dusted with a pigmented powder that will adhere to the sticky areas to form the image.

Color images result when cyan, magenta, and yellow powder are applied to successive layers of the photopolymer after each layer has been exposed through a halftone positive (color separation). The resulting colors perceived by the human eye are governed by the relative amount of each of the applied colors that occupies an area.

Color separations are produced from Landsat CCT's by generating on the film writer a halftone positive transparency for yellow using band 4 data, magenta using band 5 data, and cyan using band 7 data. Each Landsat pixel is represented on the halftone by a 16-pixel subset in a

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* Conventional halftones have a constant number of dots per unit area. Shading is obtained through the dot size.

4- by 4-pixel array. Shading on the color separations is obtained by controlling the number of pixels in each subset that are exposed (black). The number of exposed subset pixels for a given Landsat pixel is a function of the radiance level recorded on the CCT for the corresponding Landsat pixel.

A typical application of this technique is exemplified by a recently completed study of a land development project over a period of 20 months. An area on the ground approximately 3.5 by 8.0 miles in size was identified on a map (Figure 5) by the sponsor and three Landsat scenes of the area of interest were selected. No ground truth data were available to aid data processing or image interpretation. Instructions were to detect any changes within the designated study area over the period of time covered by the three scenes and display the results in an easy-to-use form.

Digital data for each of the three selected scenes were first processed to correct for skew and pixel shape. The range and distribution of band 4, 5, and 7 radiance levels were then determined. As a basis for producing the color shadings on the final product, the radiance levels were separated into five classes as shown in the table below:

	Class Range, CCT Radiance Level		
Class	Band 4 - Yellow	Band 5 - Magenta	Band 7 - Cyan
	Scene 1809-16013, 10 Oct 74		
1	0-18	0-12	0-7
2	19-21	13-16	8-12
3	22-24	14-20	13-17
4	25-27	21-24	18-22
5	28-63	25-63	23-63
	Scene 2247-16000, 26 Sep 75		
1	0-13	0-11	0-12
2	14-17	12-16	13-19
3	18-21	17-21	20-26
4	22-25	22-26	27-33
5	26-63	27-63	34-63

Class	Class Range, CCT Radiance Level		
	Band 4 - Yellow	Band 5 - Magenta	Band 7 - Cyan
		Scene 5421-15274, 13 Jun 76	
1	0-20	0-13	0-14
2	21-25	14-18	15-19
3	26-30	19-23	20-29
4	31-35	24-28	25-29
5	36-63	29-63	30-63

Subset pixel combinations were then established to control which subset pixels would be exposed on film when a CCT radiance value fell in a particular class. The combinations that were selected were unique to each color and each class as can be seen in Figure 6. Two rules were applied in the selection of subset combinations. First, the number of subset pixels exposed at any one time could not exceed 75 percent. Second, the location of selected pixels in the subset array must be such that overlay with pixels on the other color separations would be minimized in order to avoid moire patterns on the color composite.

Cyan, magenta, and yellow halftone color separations were then made in the following manner. If a band 4 radiance level of 23 occurred on the CCT for scene 1809-16013, for example, this Landsat pixel was a class 3 pixel and was represented by the class 3 subset combination shown in Figure 6 for band 4 - yellow. Exposure on film was made according to the combination shown to produce the halftone color separation.

The resulting color separations were then used to produce on Cromalin the color composites shown in Figure 7.

A cursory examination of the images shows horizontal striations on all three images; they are particularly prevalent in Scene No. 5421-15274. These striations are due to satellite scanner noise, often referred to as sixth-band noise and in no way relate to conditions that may have existed on the terrain surface. Techniques are available at the WES to minimize or eliminate the effects of scanner noise, but they were not employed in connection with this work. In spite of the noise, several changes in the area over the 20-month time period are apparent.

a. Tonal contrasts. The study area is generally lighter in tone than the surrounding area, suggesting that much of the dense vegetation in the area has been cleared. Obvious exceptions are the large square area near the center of the area of interest and the small square area at the far right of the area of interest and somewhat below the large square area. Both of these areas have coloring similar to the large area surrounding the area of interest, suggesting that vegetation has remained uncleared in these areas. When the images in Figure 7 are compared with the area outlined on the map (Figure 5), the large area can be seen to correspond to Section 16 of Township 22 North, Range 3 East. The small area corresponds to the southeast quarter of Section 23, Township 21 North, Range 4 East, which is outside the bounded area of interest.

b. Water distribution. The areas covered by water are clearly indicated by different shades of blue. In general, the darker shades of blue denote deeper water and the lighter shades denote shallow water or very wet soil. Thus, it appears that a substantial portion of the area of interest was covered with water on 10 October 1974. However, on 26 September 1975, the area was dry except for a few areas of comparatively shallow water or wet soil. On 13 June 1976 a substantial area is covered with shallow water or wet soil. Although much of the same area was covered with water on 10 October 1974, the depth of water appears to be less on 13 June 1976.

c. Vegetation. In these false-color images, the brown, red, pink, and green areas are probably sparse vegetation of different types and densities. Thus much of the area of interest was covered with some form of vegetation on 26 September 1975. Smaller areas appear to have been covered with vegetation on 10 October 1974 and 13 June 1976 or else the vegetation is obscured by water.

Digital comparison of Landsat scenes. Digital comparison of two scenes requires each pixel in one scene to be compared with its corresponding pixel in the other scene. It follows that the location of each pixel in one scene must be known with respect to the location of its corresponding pixel in the other scene. Since the corrections for skew and pixel shape are not sufficient for this purpose, the digital data for one scene (hereinafter called the working scene) must be corrected to achieve geometric accordance with the other scene (hereinafter called the reference scene).

As has been previously stated, as long as the location of each pixel value recorded on a CCT remains unchanged with respect to each other value, the geometric integrity of the image produced from the CCT will be retained. Conversely, an image can be geometrically changed by systematically changing the relative position of pixel values on the CCT. This is done at the WES with a computer program, ACCLIN, which was written for the PDP-15 computer.

Program ACCLIN is an adaptation of a set of equations developed by K. W. Wong* for transforming the coordinates of transfer points into a calibrated system. Coefficients required for operation of ACCLIN are derived from a computer program (POLY 20) which was developed by Wong to determine the coefficients of a best-fitting polynomial for the x and y coordinates separately by the method of simultaneous least-squares adjustment, the x and y translation errors (A0 and B0, respectively), and rotational error (θ).

The Program ACCLIN assumes an imaginary grid which contains 3237 scan lines with 3500 pixels per scan line. The grid contains imaginary pixels each of which has an identifiable x-y location in the grid. The problem is to find in the Landsat CCT data (which for purposes of this discussion is considered as an array of pixels in a distorted, translated, and rotated grid) the address of the reflectance value to be placed at each location in the imaginary (undistorted) grid. To do this two pairs of simultaneous equations were solved. The first pair of equations is stated as follows:

$$x_r = a_1x + b_1y + c_1 + x \qquad (1)$$

$$y_r = a_2x + b_2y + c_2 + y \qquad (2)$$

where

x_r, y_r = coordinates of pixels in the undistorted, untranslated, unrotated grid.

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* Wong, K. W., "A Computer Program Package for the Geometric Analysis of ERTS-1 Images," Report UILU-ENG-74-2005, Mar 1974, University of Illinois at Urbana-Champaign, Urbana, Illinois.

a_1, b_1, c_1, a_2, b_2, c_2 = coefficients from solution of POLY20.

x, y = coordinates of reflectance values in the distortion-corrected grid.

Solution of these two equations simultaneously gives the address of the reflectance value in a distortion-corrected, but untranslated and unrotated grid. Translation errors in x and y and rotational errors must be corrected before the address of the proper reflectance value on the CCT can be determined. This is done by solving the second pair of simultaneous equations:

$$x = (x_i - AO) \cos \theta + (y_i - BO) \sin \theta \qquad (3)$$

$$y = -(x_i - AO) \sin \theta + (y_i - BO) \cos \theta \qquad (4)$$

where

x, y = coordinates of reflectance values in the distortion-corrected grid (from solution of Equations 1 and 2 above).

x_i, y_i = location of reflectance value on Landsat CCT to be put at location x_r, y_r in imaginary grid.

AO, BO, θ = coefficients from solution of POLY20.

Equations 1-4 are used in the following way. The address of the first pixel in the first row of pixels in the imaginary (undistorted) grid (1,1) is substituted for x_r, y_r in Equations 1 and 2. Values for x and y from solution of Equations 1 and 2 are used in Equations 3 and 4 to solve for x_i, y_i. If x_i and y_i are not integers, the values are rounded to the nearest whole number to retain the integrity of the pixel values recorded on the CCT. This process is repeated for each pixel in each row of the imaginary grid, and the results are recorded on magnetic tape. When the process is completed, the magnetic tape contains the address on the Landsat CCT of each reflectance value to be placed in the imaginary grid.

This tape (hereinafter called the address tape) is then used as a director for a search of values on the Landsat CCT. The first address on the address tape is that of the reflectance value on the CCT to be

placed at location 1,1 in the imaginary grid. The CCT is then searched again until the address of the reflectance value to be placed at 2,1 is found and the reflectance value at this address is placed at 2,1 in the imaginary grid. This process is repeated until values for the first row of pixels in the imaginary grid have been found. These values are then recorded on magnetic tape. Each successive row in the imaginary grid is filled with pixel values in this manner, and the results are recorded on magnetic tape. The resulting tape is in image format.

Figure 8 presents a comparison of an uncorrected Landsat overlay showing a portion of the Mississippi River in the vicinity of Vicksburg, Mississippi, and the overlay geometrically corrected by this process. The coordinates of seven transfer points were used to calculate the correction coefficients and the translation and rotational errors. For clarity in this example, the CCT data were preprocessed so that only water bodies are shown on the overlays. The results are overlaid on Corps of Engineers map NH 15-12, which has a Universal Transverse Mercator projection.

In the uncorrected overlay, which was registered at the top of the map at the time this reproduction was made, the errors appear to be cumulative with increasing distance southward. In addition, a very slight rotational error becomes apparent with increasing distance southward. These errors do not appear in the corrected overlay.

The correction required to achieve geometric accordance of the Landsat scene and the map can be more clearly seen when the uncorrected and corrected overlays are positioned on a grid, as shown in Figure 9. Almost no correction was required at the north (upper) end of the scene, but the errors were cumulative, requiring correction in excess of 500 m near the south (lower) end of the scene.

In a study of the effects of flooding in the Lower Mississippi River Valley, two Landsat scenes (Figure 10) showing a portion of the Mississippi River in the vicinity of Vicksburg, Mississippi, were digitally compared. The working scene (scene 1286-16080) showed the area during a time when the river was flooded. The reference scene (scene 1070-16070) covered the same area during a normal within-bank river

stage. For clarity, the CCT data for both scenes were preprocessed so that land and water pixels were identified and only water bodies would be shown in the results. The working scene was geometrically corrected to the reference scene using the coordinates of 14 transfer points. Then the two scenes were digitally compared in the following way:

- a. If a water pixel in the working scene had a corresponding water pixel in the reference scene, a "zero" was recorded on an output tape.
- b. If a land pixel in the working scene had a corresponding land pixel in the reference scene, a "zero" was recorded.
- c. If a land pixel in the working scene had a corresponding water pixel in the reference scene, a "zero" was recorded.
- d. If a water pixel in the working scene had a corresponding land pixel in the reference scene, a "255" was recorded.

The results of comparing each pixel in the working scene with its corresponding pixel in the reference scene was recorded on tape for subsequent use in producing an image with the film reader/writer. Thus, when a water pixel in the flooded scene had a corresponding land pixel in the reference scene, black would be recorded on the film. Any other pixel relations would result in no exposure of the film.

Prior to producing the final overlay, the data were again transformed to achieve accordance with a UTM map of a portion of the area covered by the scene. The resulting CCT was then used to produce the overlay (Figure 11) showing land areas covered with water during the 1973 flood of the Lower Mississippi River Valley.

Summary

Since the launch of the first Landsat satellite, over 30 computer programs have been developed at the WES to extract and interpret digitized image data and present the results in several useful forms. Used in different combinations, these programs provide the capability to perform a large number of tasks in furtherance of Corps of Engineer and Department of the Army requirements.

This paper has discussed a technique for producing suspended material distribution maps by spectrum matching and two different techniques

for detecting time-dependent changes recorded by the Landsat MSS--computer-generated false color composites for visual interpretation and detection by pixel-for-pixel comparison. Unfortunately, the scope of this paper has restricted discussion to general procedures employed and an example of each technique. As a result the different combinations of the basic computer programs that are used are not readily apparent.

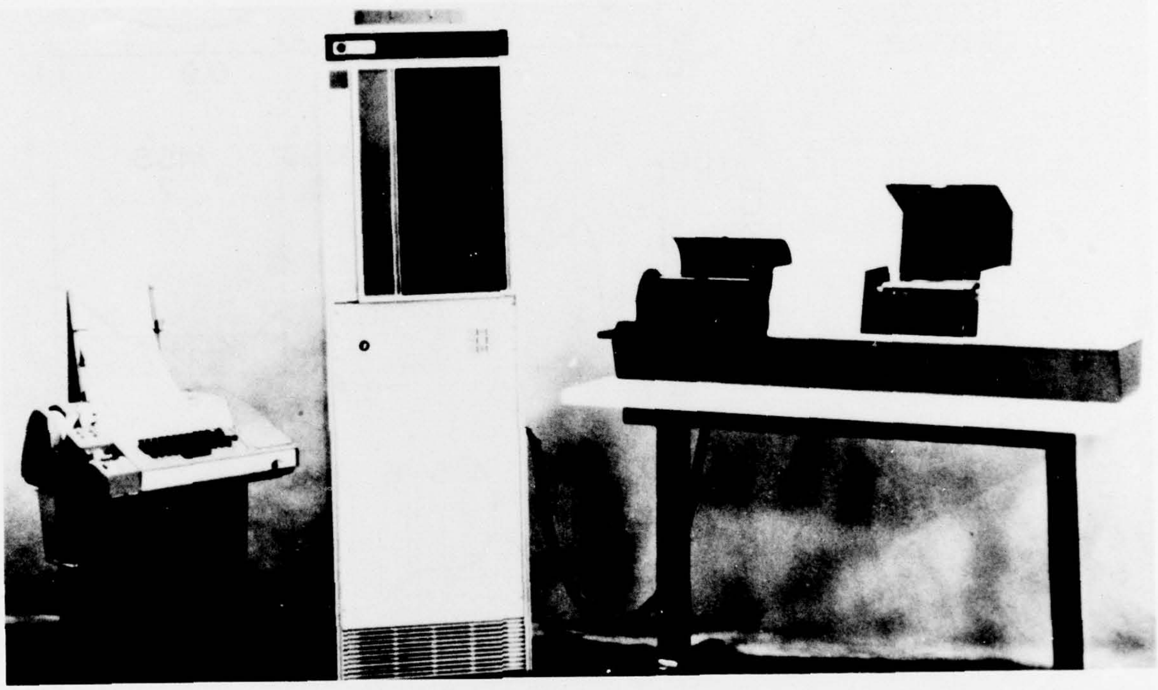


Figure 1. Film reader/writer

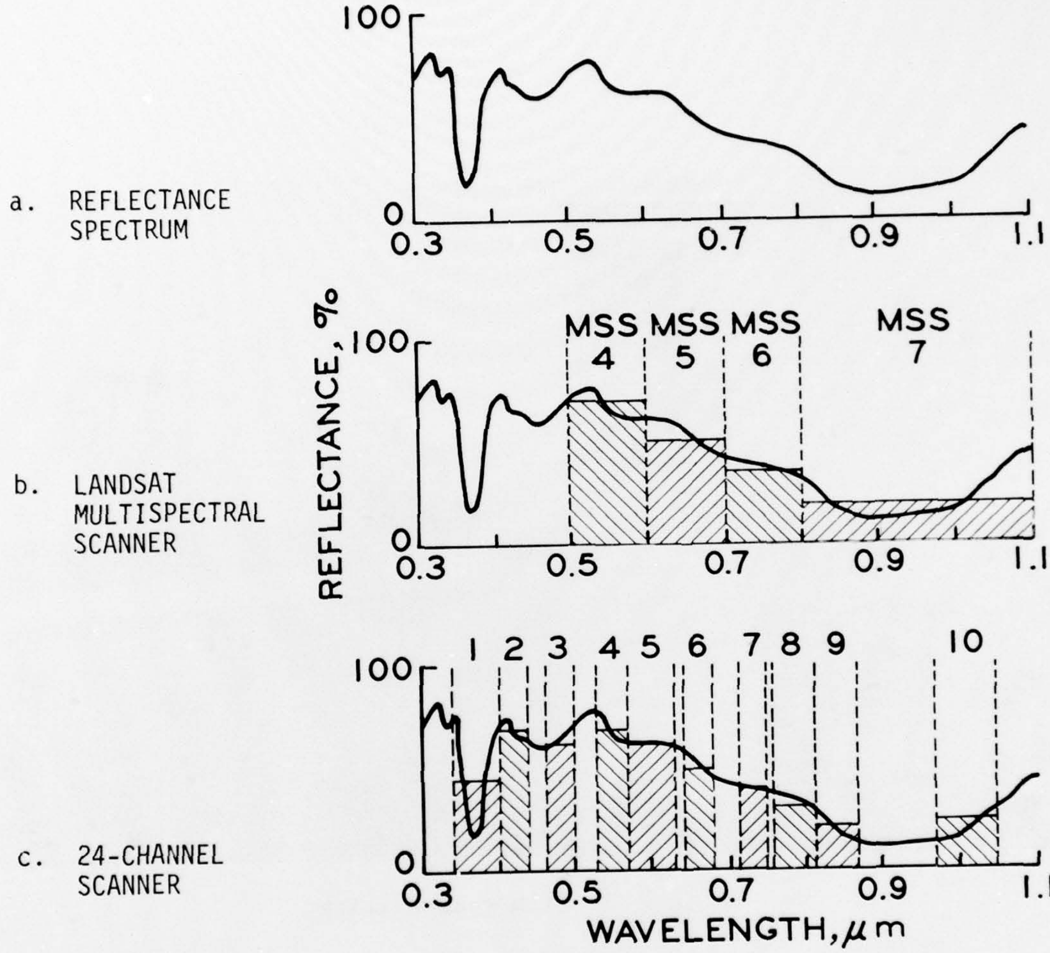


Figure 2. Reflectance specturm as defined by two multispectral remote sensors

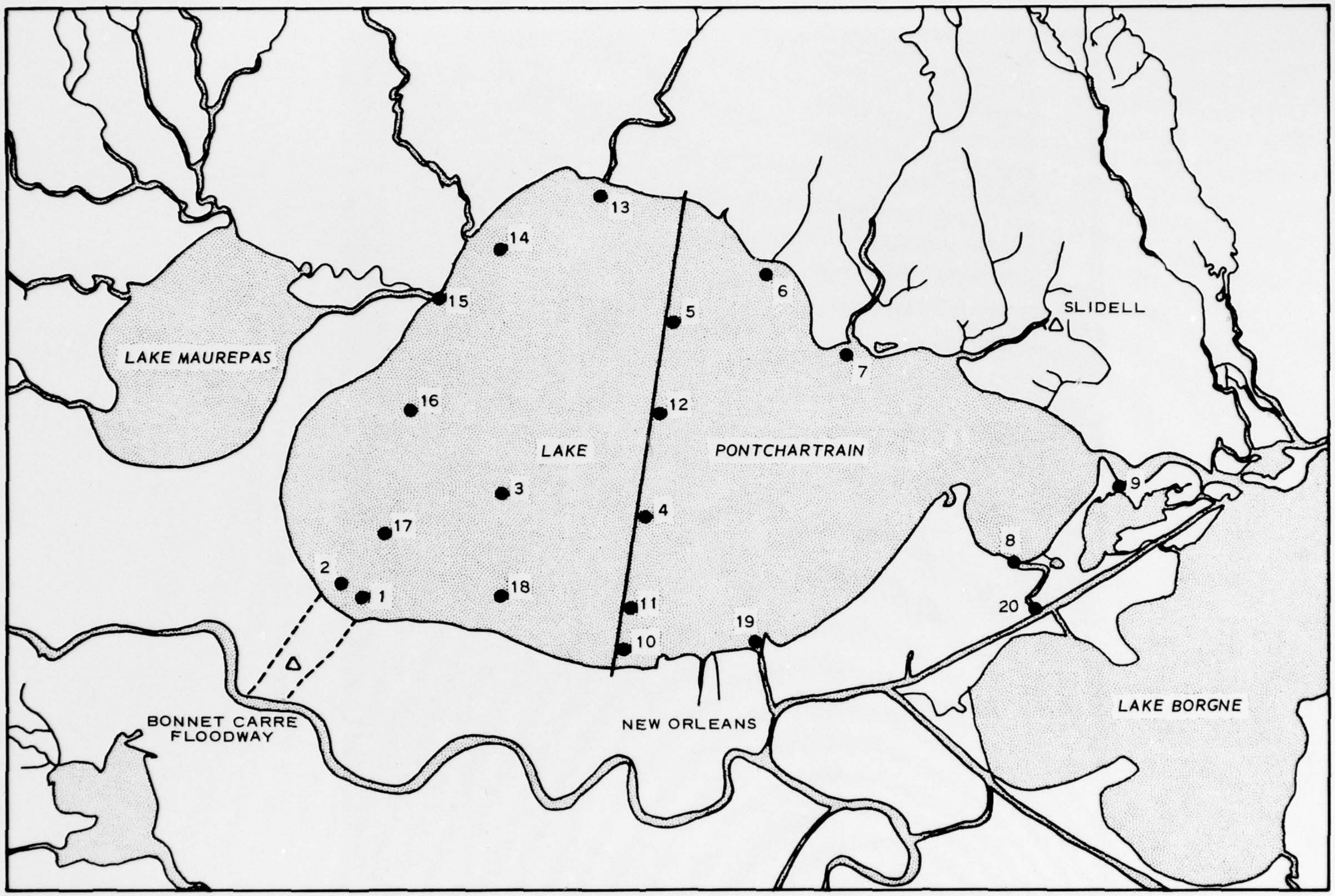


Figure 3. Locations of sampling points - Lake Pontchartrain, La.

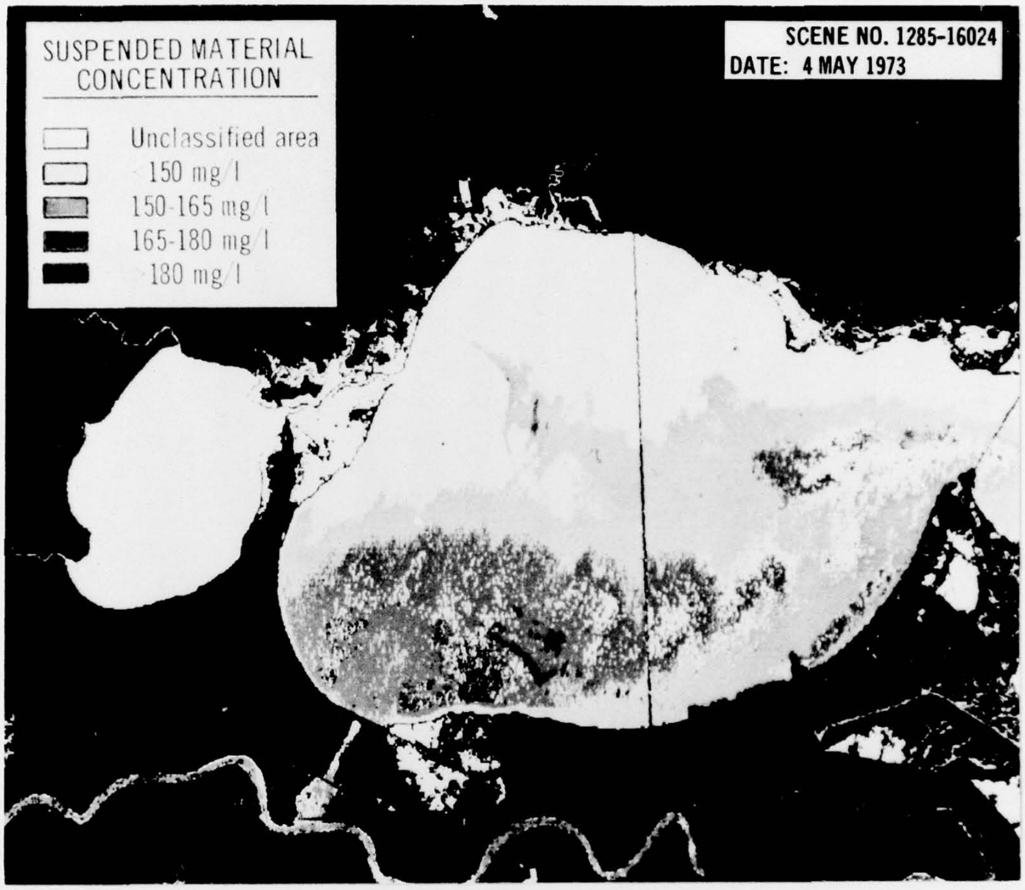


Figure 4. Suspended material distribution
Lake Pontchartrain, La.

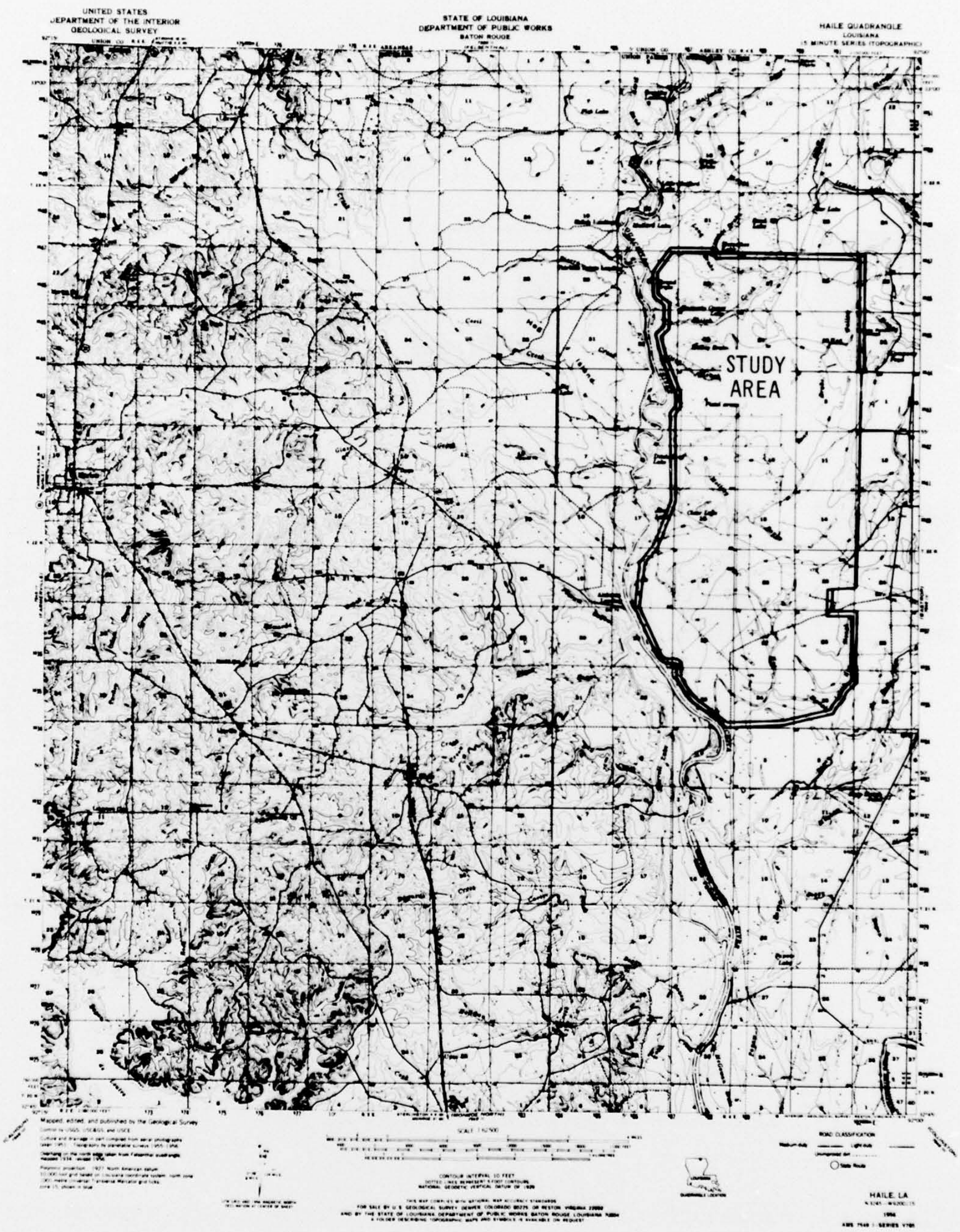


Figure 5. Map of study area

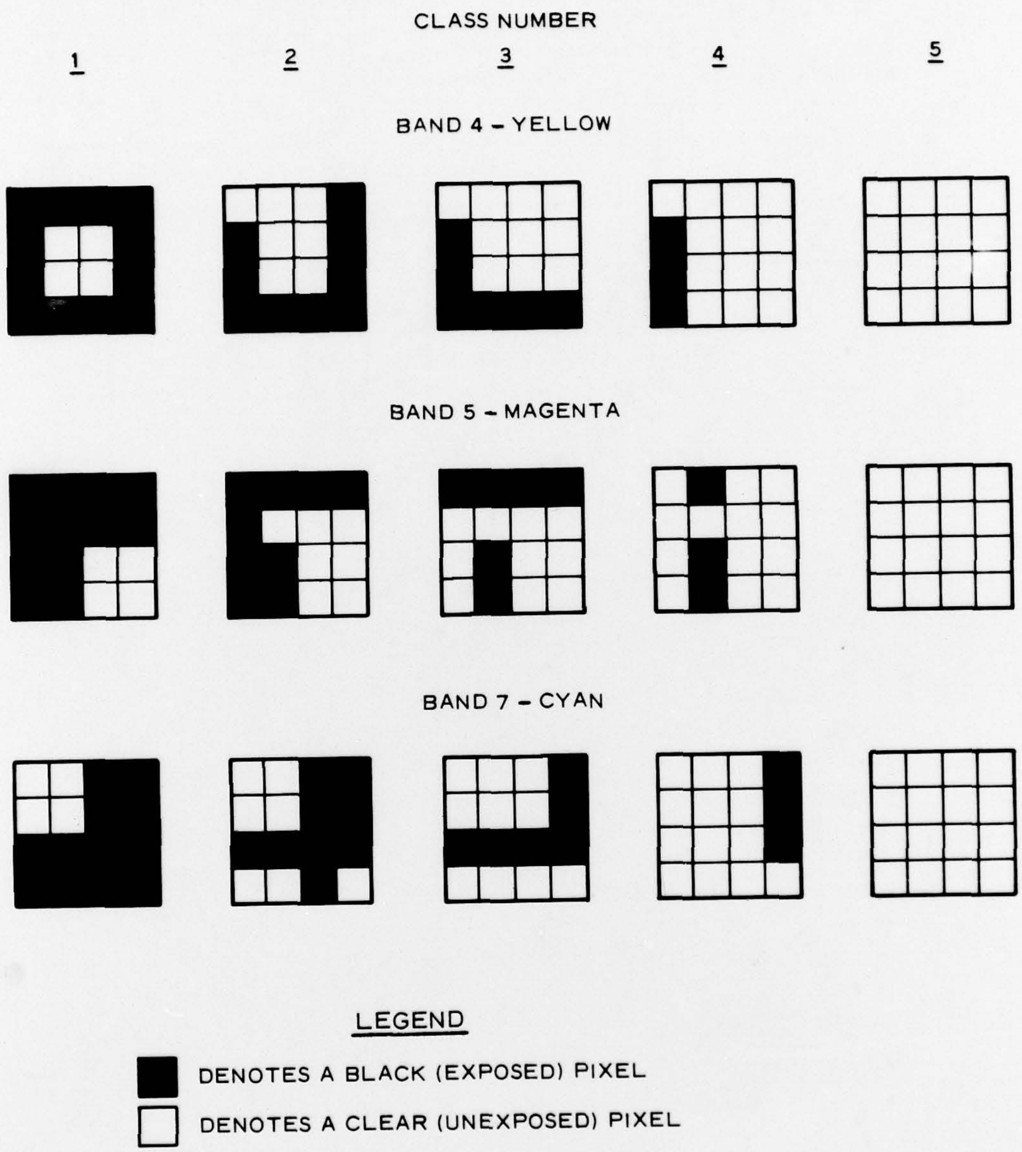


Figure 6. Subset pixel combinations used to make color separations

SCENE: 1809-16013
DATE: 10 Oct 1974

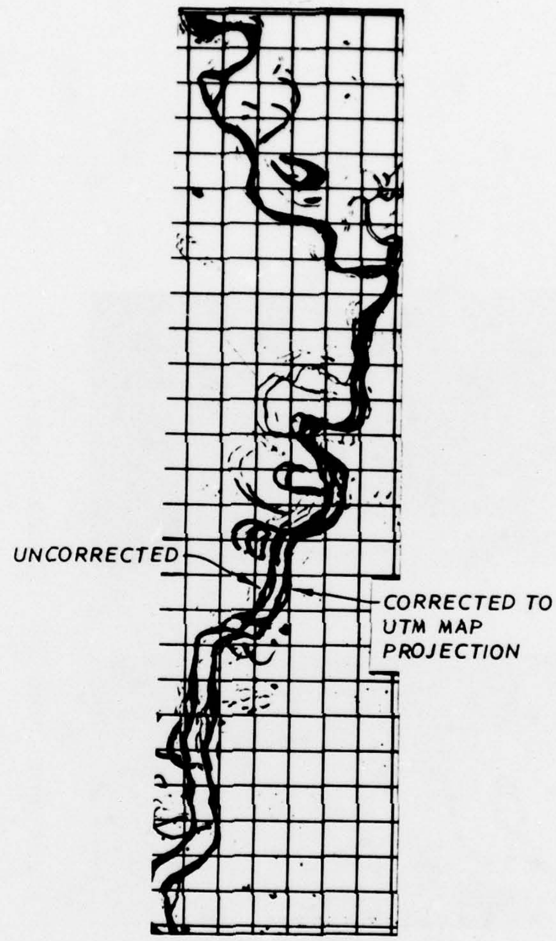
SCENE: 2247-16000
DATE: 26 Sep 1975

SCENE: 5421-15274
DATE: 13 Jun 1976

Figure 7. False color images from color separations produced by digital processing

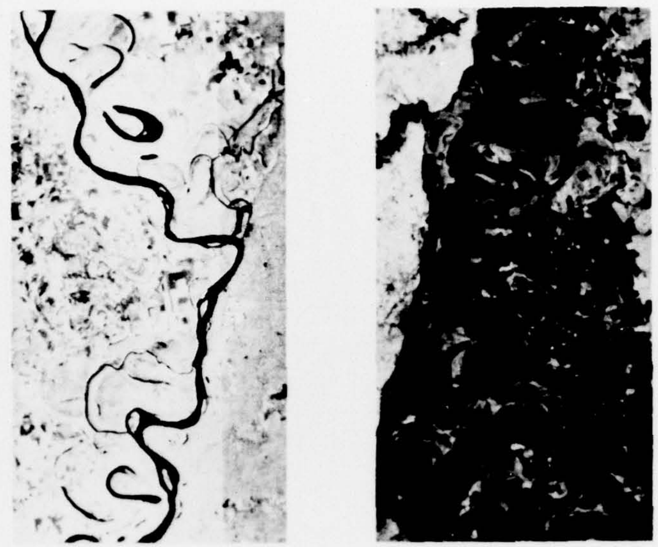
Uncorrected **Corrected**

Figure 8. Comparison of uncorrected and corrected overlays



SCENE: 1070-16070
DATE: 1 OCT 1972
SCALE: 1:1,152,500

Figure 9. Example of Landsat scene corrected to Universal Transverse Mercator map projection



SCENE: 1070 - 16070 SCENE: 1286 - 16080

Figure 10. Landsat scenes digitally compared for study of flooding

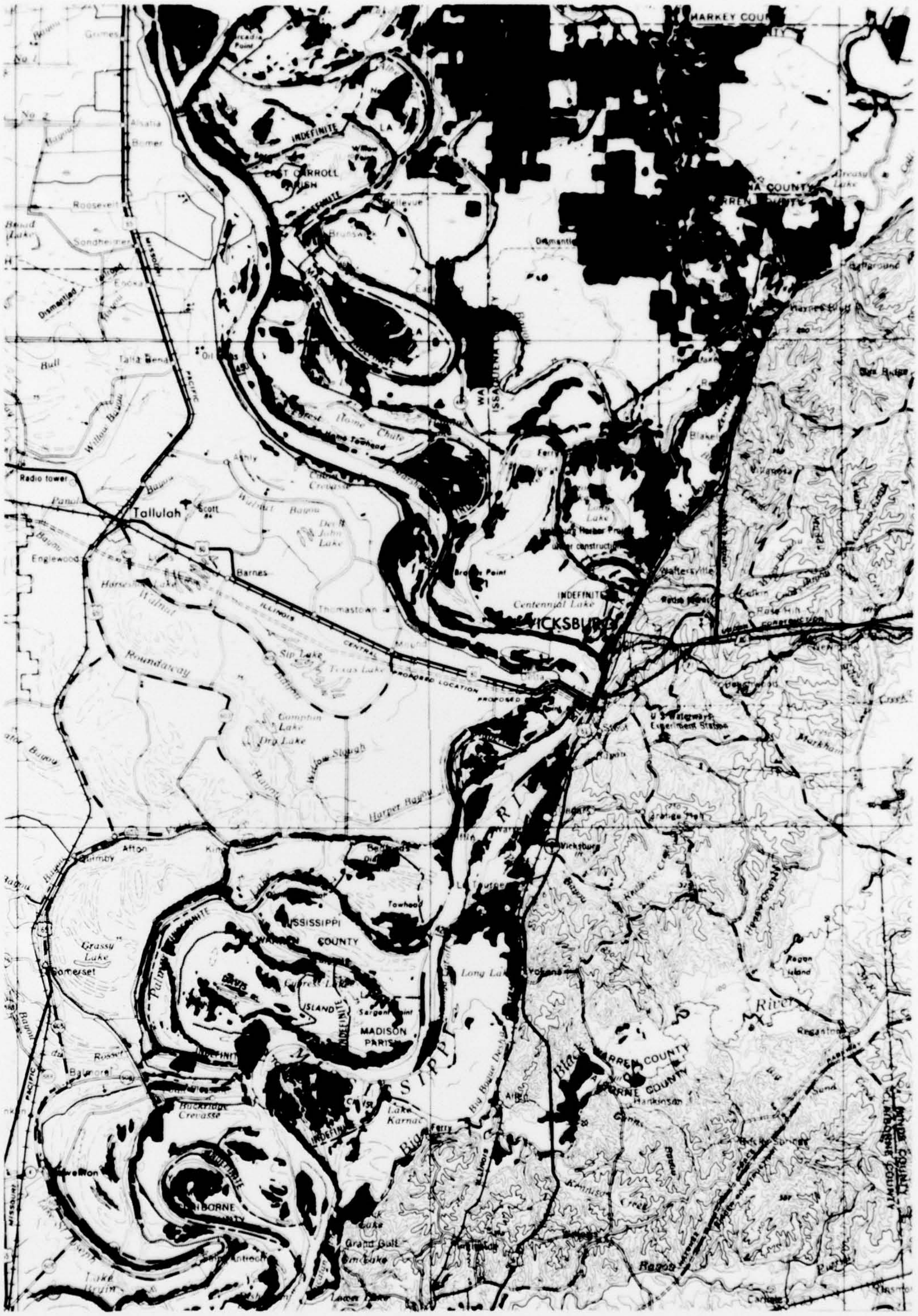


Figure 11. Overlay showing land areas covered with water during the 1973 flood of the Lower Mississippi River Valley

APPENDIX A: OPERATIONAL COMPUTER PROGRAMS FOR DIGITAL IMAGE PROCESSING

1. Over 30 different computer programs have been developed at the WES that provide the capability to perform the following listed operations on digitized image data:

   a. Demultiplex multiband computer-compatible (CCT) data.

   b. Convert radiance counts recorded on Landsat CCT's to radiance values in mW/cm^2-sr.

   c. Perform statistical analyses of pixel values in terms of radiance count, radiance or optical density values and display the results as (1) tabular lists in columnar form, (2) number arrays printed at locations on page determined by pixel location in the data array, (3) x-y plots, (4) bar graphs.

   d. Produce histograms.

   e. Calculate latitude and longitude of any point (pixel) in an array of pixels defining a Landsat scene or portion(s) thereof.

   f. Calculate centroid of any feature of interest appearing in a digitized image.

   g. Estimate feature size.

   h. Generate tabular listings of the latitude and longitude of the center point of water bodies and the estimated size of each.

   i. Merge CCT data for images of two or more adjacent geographic areas to produce an image of the entire area free of match lines.

   j. Extract radiance value from CCT data for each of the four Landsat spectral bands. Match spectral signatures comprised of the four band data with one of a set of reference spectral signatures.

   k. Rectify data to achieve geometric accordance with a map or another image.

   l. Digitally overlay images and detect time-related changes that have occurred.

   m. Filter digitized image data to reduce "noise."

   n. Correct distortions due to aircraft or spacecraft attitude and earth's rotation.

   o. Adjust shape of Landsat pixels to correspond to shape of Photomation pixel.

p. Digitally enlarge or reduce a selected portion(s) of a digitized image.

q. Produce land-use maps from Landsat data.

r. Produce color separation negatives or positives for purposes of making color composite images of Landsat scenes or multicolor thematic maps.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Williamson, Albert N

Innovations in digital image processing / by Albert N. Williamson. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1978.

20, [11], 2 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; M-78-4)

1. Computer programs. 2. Data processing. 3. Digital computers. 4. Digital image processing. 5. Digital systems. 6. Landsat (Satellite). 7. Photographic images. 8. Photointerpretation. 9. Pixels. 10. Remote sensing. I. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; M-78-4)

TA7.W34m no.M-78-4